Units and Dimension

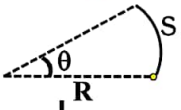
System of Units

	Length	Mass	Time
CGS	Centimetre	Gram	Second
FPS	Foot	Pound	Second
MKS	Metre	Kilogram	Second

Fundamental Quantities

	SI unit	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Temperature	Kelvin	K
Electric Current	Ampere	A
Luminous Intensity	Candela	cd
Amount of Substance	mole	mol

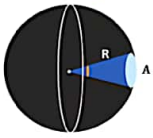
Plane angle



$$\text{Plane Angle} = \frac{\text{Arc Length}}{\text{Radius}}$$

	SI unit	Symbol
Plane Angle	radian	rad
Solid Angle	Steradian	sr

Solid angle



$$\text{Solid Angle} = \frac{\text{Area}}{(\text{Radius})^2}$$

Applications of Dimensions

1. Principle of Homogeneity

Only same type of physical quantities can be added or subtracted $x = A + B$ $x = A - B$

$[x] = [A] = [B]$

2. Conversion of Units

$1\ m = 100\ cm = 1000\ mm$

$n_1u_1 = n_2u_2 = n_3u_3$ $nu = \text{constant}$

When unit become smaller, numerical value increase.

3. To derive relationship between physical quantities

Limits of Dimensions

1. The relation derived from this method gives no information about the dimensionless constants.
2. The dimensional quantity to be derived must be of multiplication type. We cannot derive relations if addition or subtractions are involved.
3. This method is not applicable when unknown variables are more than equations present.

A physical quantity is expressed as

$n\ u$

Numerical Value — Unit

Derived Quantities

Quantities which can be derived from fundamental quantities.

Dimensions

Quantity	Dimension Symbol
Length	L
Mass	M
Time	T
Temperature	θ, K
Electric Current	I, A
Amount of Substance	Mol
Luminous Intensity	cd

- ✓ Angles and trigonometric functions are dimensionless quantity
  $[\theta] = [L^0]$ $[\sin\theta] = M^0L^0T^0$
- ✓ All exponents are dimensionless.
- ✓ Logarithmic functions and it's arguments are dimensionless
  $[a] = M^0L^0T^0$
  $[\log a] = M^0L^0T^0$

Dimensionally correct equation may or may not be correct but dimensionally incorrect equation must be incorrect.

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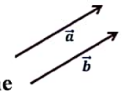
Two vectors are said to be equal if, and only if, they have same magnitude and the same direction.



$\vec{a} = \vec{b}$

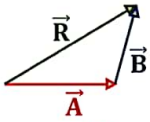
$0° \leq$ Angle between two vectors $\leq 180°$

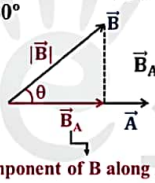
Parallel Vectors	Anti-Parallel Vectors
Same direction and angle between vectors is 0°	Opposite direction and angle between vectors is 180°

Triangle rule of vector addition

$\vec{A} + \vec{B} = \vec{R}$

$|\vec{R}| \neq |\vec{A}| + |\vec{B}|$



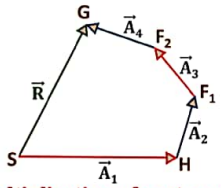


component of B along A

$\vec{B}_A = |\vec{B}| \frac{(\vec{A} \cdot \vec{B})}{|\vec{A}|\,|\vec{B}|} \hat{A}$

Polygon rule of vector addition

$\vec{R} = \vec{A}_1 + \vec{A}_2 + \vec{A}_3 + \vec{A}_4$



Multiplication of vector with real number

magnitude $|\lambda|\,|\vec{A}|$, direction remains the same.

Scalar Product (Dot Product) of two Vectors

$\vec{A} \cdot \vec{B} = |\vec{A}||\vec{B}|\cos\theta$

$\vec{A} \cdot \vec{B} = \vec{B} \cdot \vec{A}$

$\vec{A} \cdot (\vec{B} + \vec{C}) = \vec{A} \cdot \vec{B} + \vec{A} \cdot \vec{C}$

$\hat{i} \cdot \hat{i} = 1 \quad \hat{j} \cdot \hat{j} = 1 \quad \hat{k} \cdot \hat{k} = 1$

$\hat{i} \cdot \hat{j} = 0 \quad \hat{i} \cdot \hat{k} = 0 \quad \hat{k} \cdot \hat{j} = 0$

To find angle between two vectors $\cos\theta = \frac{\vec{A} \cdot \vec{B}}{|\vec{A}||\vec{B}|}$

Vectors

$|\vec{A}|$ = Magnitude of $\vec{A}$

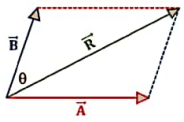
Parallelogram rule of vector addition

$R = \sqrt{A^2 + B^2 + 2AB\cos\theta}$

When $\theta = 0°$ $\quad R_{max} = A + B$

When $\theta = 180°$ $\quad R_{min} = |A - B|$

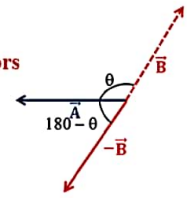
$|\vec{R}|_{min} \leq |\vec{R}| \leq |\vec{R}|_{max}$



Subtraction of vectors

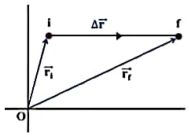
$|\vec{A} - \vec{B}| = \sqrt{A^2 + B^2 - 2AB\cos\theta}$

$|A - B| \leq |\vec{A} - \vec{B}| \leq A + B$



Displacement vector

$\Delta\vec{r} = \vec{r}_f - \vec{r}_i$



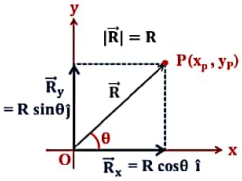
$\vec{A} \cdot \vec{A} = |\vec{A}|^2$

Zero vector

$\vec{A} - \vec{A} = \vec{0}$

Resolution of a Vector into Components

Rectangular Components



$\vec{R} = \vec{R}_x + \vec{R}_y$

$\vec{R} = R\cos\theta\,\hat{i} + R\sin\theta\,\hat{j}$

$|\vec{R}| = \sqrt{R_x^2 + R_y^2}$

$|\vec{R}| \geq 0$

$\tan\theta = \frac{R_y}{R_x}$ $\qquad \hat{R} = \frac{\vec{R}}{|\vec{R}|} = \frac{R_x\hat{i} + R_y\hat{j}}{\sqrt{R_x^2 + R_y^2}}$

Position Vector $\overrightarrow{OP} = \vec{r} = x_p\hat{i} + y_p\hat{j}$

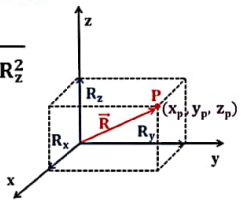
Representation of vector in 3D

$\vec{R} = R_x\hat{i} + R_y\hat{j} + R_z\hat{k}$

$R = |\vec{R}| = \sqrt{R_x^2 + R_y^2 + R_z^2}$

Position Vector

$\vec{r} = x_p\hat{i} + y_p\hat{j} + z_p\hat{k}$



Unit vector

$\hat{A} = \frac{\vec{A}}{|\vec{A}|}$

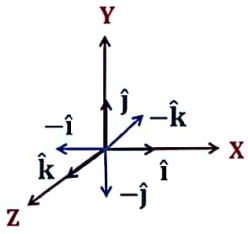
magnitude = 1

purpose is to describe a direction in space

$|\hat{i}| = 1 = |-\hat{i}|$

$|\hat{j}| = 1 = |-\hat{j}|$

$|\hat{k}| = 1 = |-\hat{k}|$



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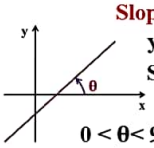
y	differentiation	Integration
x^n	nx^{n-1}	$\int x^n\,dx = \frac{x^{n+1}}{n+1} + c$
ℓnx	$\frac{1}{x}$	$\int \frac{1}{x}\,dx = \ln x + c$
e^x	e^x	$\int e^x dx = e^x + c$
$\sin x$	$\cos x$	
$\cos x$	$-\sin x$	$\int \sin x\,dx = -\cos x + c$
$\tan x$	$\sec^2 x$	
$\cot x$	$-\text{cosec}2x$	$\int \cos x\,dx = \sin x + c$
C	0	
$y_1 + y_2$	$\frac{dy_1}{dx} + \frac{dy_2}{dx}$	$\int (f(x) + g(x))dx$
$y_1 - y_2$	$\frac{dy_1}{dx} - \frac{dy_2}{dx}$	$= \int f(x)dx + \int g(x)dx$
$y_1 . y_2$	$y_1\frac{dy_2}{dx} + y_2\frac{dy_1}{dx}$	
$\frac{y_1}{y_2}$	$\frac{y_2\frac{dy_1}{dx} - y_1\frac{dy_2}{dx}}{y_2^2}$	$\int kf(x)dx = k\int f(x)dx$

If sign of a and v are same then speed is increasing and if sign are opposite then speed is decreasing

Kinematics 1D

Slope



$y = (m)x + c$

Slope $(m) = \tan\theta$

$0 < \theta < 90°$ slope = +ve

$90° < \theta < 180°$ slope = −ve

$\theta = 0°$ slope = 0

For particle under constant acceleration

(1) $v = u + at$

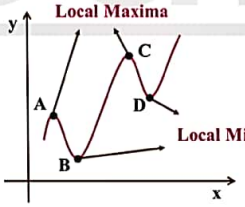
(2) $s = ut + \frac{1}{2}at^2$

(3) $v^2 = u^2 + 2as$

(4) $s = \left(\frac{v+u}{2}\right)t$

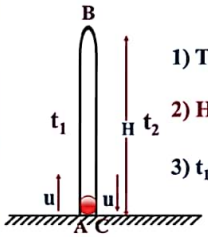
(5) $s = vt - \frac{1}{2}at^2$

Local maxima and Local minima



	$\frac{dy}{dx}$	$\frac{d^2y}{dx^2}$
Local maxima	0	-ve
Local minima	0	+ve

Motion under gravity



1) $T_{\text{ime of flight}} = \frac{2u}{g}$

2) $H_{max} = \frac{u^2}{2g}$

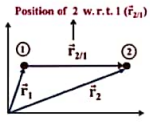
3) $t_1 = t_2 = \sqrt{\frac{2H}{g}} = \frac{u}{g}$

Relative motion

$\vec{r}_{2/1} = \vec{r}_2 - \vec{r}_1$

$\vec{v}_{2/1} = \vec{v}_2 - \vec{v}_1$

$\vec{a}_{2/1} = \vec{a}_2 - \vec{a}_1$



Speed

Average: $< \text{Speed} > = \frac{s}{\Delta t}$

Instantaneous: Inst. Speed $= \frac{ds}{dt}$

s is distance

Velocity

Average: $< \vec{v} > = \frac{\Delta \vec{r}}{\Delta t}$

Instantaneous: $\vec{v}_{inst} = \frac{d\vec{r}}{dt}$

r is displacement (minimum distance between initial and final point)

Acceleration

Average: $< \vec{a} > = \frac{\Delta \vec{v}}{\Delta t}$

Instantaneous: $\vec{a} = \frac{d\vec{v}}{dt}$

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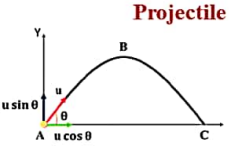
Projectile motion



$$T = \frac{2u\sin\theta}{g} = \frac{2u_y}{g}$$

$$H = \frac{u^2\sin^2\theta}{2g} = \frac{u_y{}^2}{2g}$$

Range is same for the complimentary angles.

Range is maximum when θ is 45 °

$$R = \frac{u^2\sin 2\theta}{g}$$

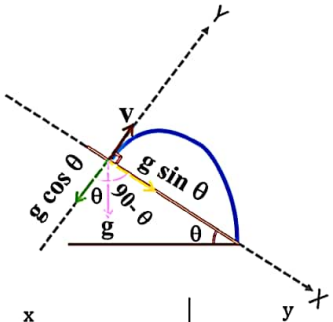
Equation of trajectory $y = x\tan\theta - \frac{gx^2}{2u^2\cos^2\theta}$

Path of particle having constant acceleration

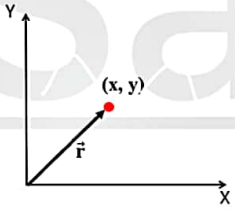
Initial Velocity (u)	Path
u = 0	Straight Line
u ≠ 0, u and a collinear	Straight Line
u ≠ 0, u and a non-collinear	Parabolic

If two particles are projected in gravitational field then during the time at flight of both particles, trajectory of one particle w.r.t. other particle will be a straight line.

Projectile on inclined plane



Kinematics 2D



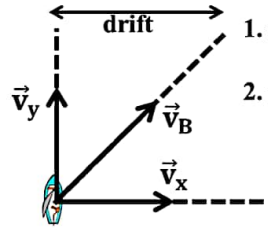
$$\vec{r} = x\hat{i} + y\hat{j}$$

$$\vec{v} = \frac{dx}{dt}\hat{i} + \frac{dy}{dt}\hat{j}$$

$$\vec{a} = \frac{d^2x}{dt^2}\hat{i} + \frac{d^2y}{dt^2}\hat{j}$$

x	y
$u_x = 0$	$u_y = v$
$a_x = g\sin\theta$	$a_y = -g\cos\theta$
$t = \frac{2v}{g\cos\theta}$	$s_y = 0$
$s_x = \frac{1}{2}g\sin\theta\left(\frac{2v}{g\cos\theta}\right)^2$	$0 = ut + \left(\frac{g\cos\theta t^2}{2}\right)$
	$t = \frac{2v}{g\cos\theta}$

River and Boat:



1. x component of $\vec{v}_B$ (i.e. along river flow) is responsible for drift.
2. y component of $\vec{v}_B$ (i.e. perpendicular river flow) is responsible for crossing the river.

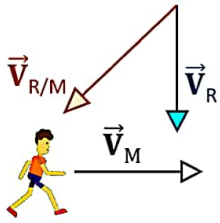
$$\vec{v}_B = \vec{v}_{B/r} + \vec{v}_r$$

Rain Man situation:

1 Man observes rain in direction of velocity of rain w.r.t. man ($\vec{v}_{R/M}$).

2. Umbrella is held in direction opposite to the velocity of rain w.r.t. man ($-\vec{v}_{R/M}$).

$$\vec{V}_{R/M} = \vec{V}_R - \vec{V}_M$$



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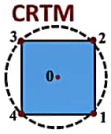
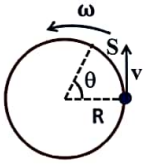


Kinematics of Pure rotation motion

$S = R\theta$

$|v| = R\omega$



1. Since distance between two particles of a rigid body remains constant, so the relative motion of one particle w.r.t. other particle is circular motion.
2. Angular velocity of all the particles about a given point of a rigid body is same
   $\omega_{1/0} = \omega_{2/0} = \omega_{3/0} = \omega_{4/0} = \omega_0$
3. This angular velocity of a rigid body about all the point of rigid body is same.

$\omega_{0/1} = \omega_{2/1} = \omega_{3/1} = \omega_{4/1}$
$\parallel$
$\omega_{1/0} = \omega_{2/0} = \omega_{3/0} = \omega_{4/0} = \omega_0$ → 'ω' of rigid body

If α = constant

$\omega_f = \omega_i + \alpha t$

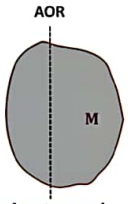
$\theta = \omega_0 t + \frac{1}{2}\alpha t^2$

$\omega_f^2 = \omega_i^2 + 2\alpha\theta$

$\theta = \left(\frac{\omega_i + \omega_f}{2}\right) t$

$\theta = \omega_f t - \frac{1}{2}\alpha t^2$

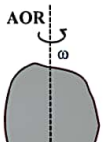
Radius of Gyration



$K = \sqrt{\frac{I}{M}}$ → RoG about an axis

$I = MK^2$

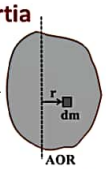
Rotational Motion

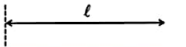


$KE_{sys} = \frac{1}{2} I \omega^2$

Moment of Inertia

$I = \int r^2\, dm$



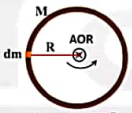


$I = \frac{M\ell^3}{3}$

$I = 0$

$I = \frac{M\ell^2}{12}$

Uniform Ring

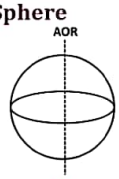


$I = MR^2$

Disk

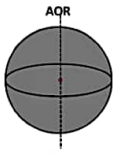
$I = \frac{MR^2}{2}$

Uniform Hollow Sphere



$I = \frac{2}{3}MR^2$

Uniform Solid Sphere



$I = \frac{2}{5}MR^2$

Moving mass parallel to AOR does not change moment of inertia.

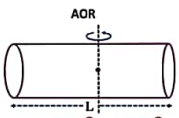
Parallel – axis theorem:

Among the given parallel axis MOI will be minimum about the axis passing through COM.

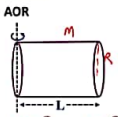
MOI about the parallel axis having same distance from COM is equal.

$I_{AA'} = I_{CC'} + Md^2$

Hollow Cylinder

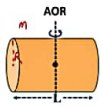


$I = \frac{MR^2}{2} + \frac{ML^2}{12}$

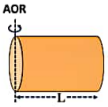


$I = \frac{MR^2}{2} + \frac{ML^2}{3}$

Solid Cylinder

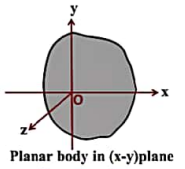


$I = \frac{MR^2}{4} + \frac{ML^2}{12}$



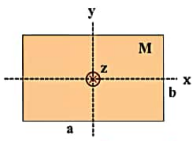
$I = \frac{MR^2}{4} + \frac{ML^2}{3}$

Perpendicular axis theorem:



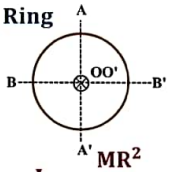
Planar body in (x-y)plane

$I_z = I_x + I_y$



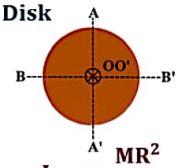
$I_z = \frac{Mb^2}{12} + \frac{Ma^2}{12}$

Ring



$I_{AA'} = \frac{MR^2}{2}$

Disk



$I_{AA'} = \frac{MR^2}{4}$

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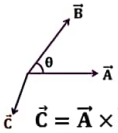
Cross Product



$\vec{C} = \vec{A} \times \vec{B}$

$|\vec{C}| = |\vec{A}||\vec{B}| \sin\theta$

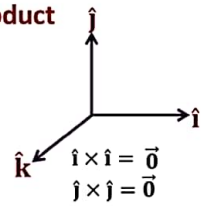
θ is angle b/w $\vec{A}$ & $\vec{B}$

Properties

$\vec{A} \times \vec{B} \neq \vec{B} \times \vec{A}$

$\vec{A} \times \vec{B} = -(\vec{B} \times \vec{A})$

$\vec{A} \times \vec{A} = \vec{0}$

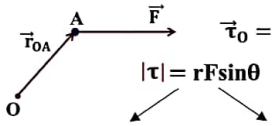


$\hat{i} \times \hat{i} = \vec{0}$ $\quad \hat{j} \times \hat{j} = \vec{0}$ $\quad \hat{k} \times \hat{k} = \vec{0}$

$\hat{i} \times \hat{j} = \hat{k}$ $\quad \hat{j} \times \hat{k} = \hat{i}$ $\quad \hat{k} \times \hat{i} = \hat{j}$

$\hat{j} \times \hat{i} = -\hat{k}$ $\quad \hat{k} \times \hat{j} = -\hat{i}$ $\quad \hat{i} \times \hat{k} = -\hat{j}$

Torque



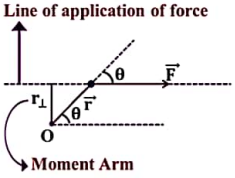
$\vec{\tau}_O = \vec{r}_{OA} \times \vec{F}$

$|\tau| = rF\sin\theta$

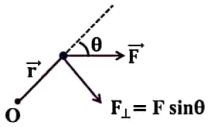
$(r \sin\theta)F$ $\quad$ $r(F \sin\theta)$

$\boxed{|\tau| = r_\perp F}$ $\quad$ $\boxed{|\tau| = rF_\perp}$

Line of application of force



Moment Arm



$F_\perp = F \sin\theta$

$F_\perp$ is perpendicular component of $\vec{F}$

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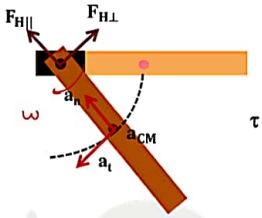
Calculation of Hinge Force



$F_H = \sqrt{F_{H||}^2 + F_{H\perp}^2}$

$(F_{H\perp})$ Perpendicular to rod

$\sum F_\perp = m(a_{CM})_t = m\alpha\frac{L}{2}$

$\tau = I\alpha \longrightarrow \alpha \longrightarrow (a_{CM})_t \longrightarrow F_{H\perp}$

$(F_{H||})$ Parallel i.e. along the rod

$\sum F_{||} = m(a_{CM})_n = m\omega^2\frac{L}{2}$

W-E Theorem $\longrightarrow \omega \longrightarrow (a_{CM})_n \longrightarrow F_{H||}$

Rotation Motion

Condition of Equilibrium

Translation Equilibrium

1) $\sum \vec{F} = 0 \Rightarrow \sum \vec{F}_x = 0,\ \sum \vec{F}_y = 0,\ \sum \vec{F}_z = 0$

Rotational Equilibrium

2) $\sum \vec{\tau} = 0$

If $\vec{F}_{net} = 0$ on a rigid body then $\vec{\tau}_{net}$ is same about every point of space.

Inertial Pulley

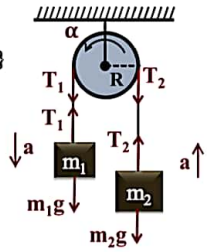
{No slipping of rope on disk}

$T_1R - T_2R = I\alpha$ ....(1)

$m_1g - T_1 = m_1a$ ....(2)

$T_2 - m_2g = m_2a$ ....(3)

$\alpha R = a$ ....(4)



Work done in terms of Torque

$W = \int \tau d\theta$ $\quad P = \tau\omega$

Force Couple

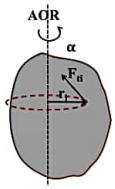
A pair of equal & opposite forces is called force couple.

Torque of force couple is same about any point of the space.

$\sum \tau_{int} = 0$

$\left(\sum \tau_{ext}\right)_{AOR} = (I)_{AOR}\alpha$

Valid only in inertial frame.



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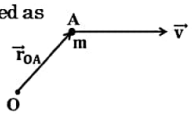
Angular Momentum of Particle

Angular Momentum of Particle about point O is defined as

$\vec{L}_O = \vec{r}_{OA} \times \vec{P}$

$= \vec{r}_{OA} \times (m\vec{v})$

$= m\vec{r}_{OA} \times \vec{v}$



where $\vec{P}$ is linear momentum of the particle present at A.

$\vec{L}_O$ is angular momentum about O.

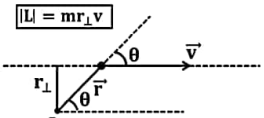
$\vec{L} = \vec{r} \times \vec{P}$

AM is also known as moment of LM.

$m(r\sin\theta)v \Rightarrow \vec{L}$ = Constant

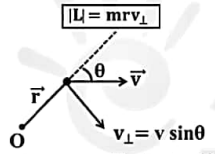
$|L| = mrv\sin\theta$

$|L| = mr_\perp v$



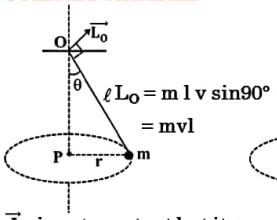
$r_\perp$ is the shortest distance from O to line of velocity.

$|L| = mrv_\perp$



$v_\perp$ is perpendicular to $\vec{r}$

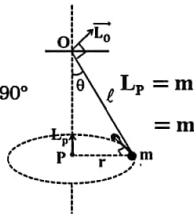
Conical Pendulum



$\ell L_O = m\,l\,v\sin 90°$

$= mvl$

$\vec{L}_O$ is not constant but its magnitude is constant.



$L_P = m\,\ell\sin\theta\,v\sin 90°$

$= mv\ell\sin\theta$

$\vec{L}_P$ is constant

Rotational Motion

Angular Momentum Conservation Principle

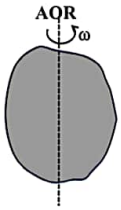
$\vec{\tau}_{net} = \frac{d\vec{L}}{dt}$ If $\vec{\tau}_{net} = 0 \Rightarrow \vec{L}$ = Constant

If $\vec{\tau}_{net}$ is zero then its A.M. is conserved.

Angular Momentum of System of Particles

$\vec{L}_{sys} = \sum \vec{L}_i$

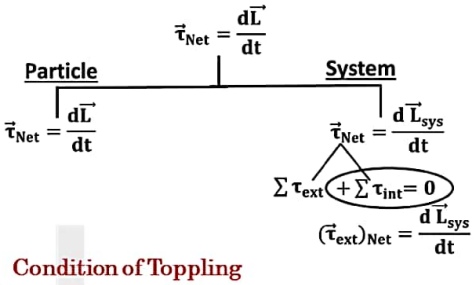
A.M. of Rigid Body Performing Pure Rotation About Fixed Axis



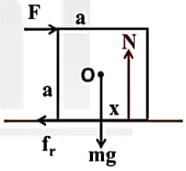
$(L_{sys})_{AOR} = I_{AOR}\,\omega$

Relation Between Torque and Angular Momentum

$\vec{\tau}_{Net} = \frac{d\vec{L}}{dt}$ valid only in inertial frame.



Condition of Toppling



$x > \frac{a}{2}$ Toppling will occur

$x = \frac{a}{2}$ On verge of toppling

$x < \frac{a}{2}$ No toppling

Angular Impulse

Linear Impulse $(\vec{I})$

$\vec{I} = \int \vec{F}\,dt$

Unit - Ns

$\vec{I}_{net} = \vec{P}_f - \vec{P}_i$

Angular Impulse $(\vec{J})$

$\vec{J} = \int \vec{t}\,dt$

Unit - Nms

$\vec{J} = \vec{r} \times \vec{I}$

$\vec{J}_{net} = \vec{L}_f - \vec{L}_i$

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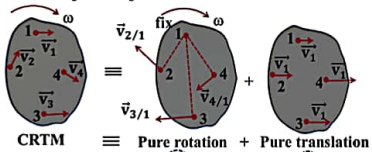
Combined Rotation + Translational Motion [CRTM]

Velocity Analysis



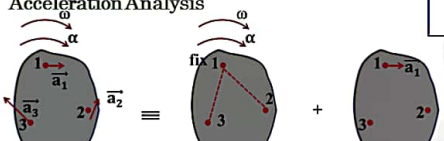
CRTM ≡ Pure rotation + Pure translation

$\vec{v}_2 = \vec{v}_{2/1} + \vec{v}_1$

$\vec{v}_3 = \vec{v}_{3/1} + \vec{v}_1$

$\vec{v}_4 = \vec{v}_{4/1} + \vec{v}_1$

Acceleration Analysis



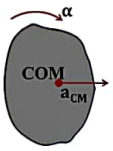
CRTM ≡ Pure rotation + Pure translation

Dynamics of CRTM

For analysing its motion we apply two equation

$\sum \vec{F}_{ext} = M\vec{a}_{CM}$

$\sum \vec{\tau}_{ext} = I\vec{\alpha}$



Dynamics of CRTM

Second equation is valid in inertial frame.

1) $\sum \vec{F} = M\vec{a}_{CM}$ 2) $\sum \vec{\tau} \asymp I\vec{\alpha}$

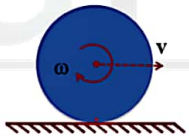
$\sum \vec{F}_{ext} = M\vec{a}_{CM}$ $\sum \vec{\tau}_{ext} = I\vec{\alpha}$

To apply second equation about non-inertial point, Pseudo force is applied at COM of body & τ of Pseudo force is also taken into account.

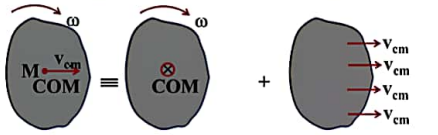
Rolling Motion

If during the motion, there is no relative slipping between the points of contact, then motion is called Rolling.

$v = \omega R$



Kinetic Energy of Rigid Body Performing CRTM

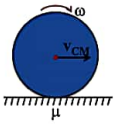


CRTM ≡ Rotational KE + Translational KE

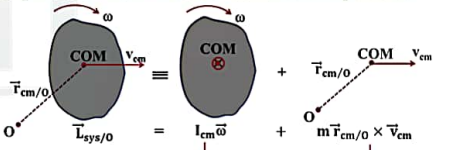
$KE = \frac{1}{2} I_{CM} \omega^2 + \frac{1}{2} M v_{CM}^2$

Keypoint

For a body performing rolling motion over a fixed surface, work done by friction force on the body will be zero as velocity of point of application of friction always zero.



Angular Momentum of R.B. Performing CRTM



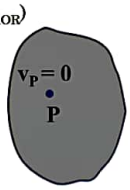
Rotational as rigid body; Pure rotation about COM

Translation as a particle

$\vec{L}_{sys/O} = I_{cm}\vec{\omega} + m\vec{r}_{cm/O} \times \vec{v}_{cm}$

Instantaneous Center of Rotation (I_{COR}) & Axis of Rotation (I_{AOR})

- Let at an instant of time velocity of point P is zero.
- To calculate velocity of other points of rigid body, rigid body can be assumed to perform pure rotation about an axis passing through point P at that instant. This point is called I_{COR} and axis passing through it is called I_{AOR}.



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GRAVITATION

ESCAPE VELOCITY

$V_e = \sqrt{\frac{2GM_e}{R}}$

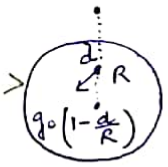
AT SURFACE $= \sqrt{\frac{GM_e}{R}} = \sqrt{2gR}$

$= 11.2$ km/s (earth)

TUNNEL

$T = 2\pi\sqrt{\frac{R^3}{GM}}$ $\left(2\pi\sqrt{\frac{L}{g}}\right)$

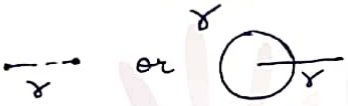
g



$g_0\left(1+\frac{h}{R}\right)^2 \approx g_0\left(\frac{1-2h}{R}\right)$

$g_0 = \frac{GM_e}{R^2}$

$U = -\frac{GM_1M_2}{r}$



SATELLITE

$V = \sqrt{\frac{GM_e}{r}}$ $T = 2\pi\sqrt{\frac{r^3}{GM_e}}$

$\frac{|PE|}{2} = |KE| = |ME|$

GEOSTATIONARY

T = 24 hrs, West to East, $\omega = 0$ (w.r.t. earth)

Parking Orbit, telecomm, weather forecast

$h = 3600$km ; $V = 3.08$ km/sec

6.67×10^{-11}

$\frac{GM_1M_2}{r^2}$

- $V < V_e$ Ellipse $\left(\frac{V_e}{\sqrt{2}}\right)$
- $V = V_e$ Parabola
- $V > V_e$ Hyperbola

- Binary Star about COM
- $g_{app} = g_0$ at pole max
- $g_{app} = g_0 - \omega^2 R_e$ (min) (at Equator)
- g_0 more at poles than Equator (Non Sph)

FIELD

M → $\frac{GM}{r^2}$

HOLLOW — ZERO — $\frac{GM}{r^2}$

SOLID — $\frac{GMr}{R^3}$ — $\frac{GM}{R^2}$

KEPLER'S LAWS

① SUN AT FOCI

② EQUAL AREA IN EQUAL TIME

AREAL $\frac{dA}{} = \frac{L}{2M}$

③ $T = 2\pi\sqrt{\frac{a^3}{GM_{SUN}}}$

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Thermodynamics

Molar Heat Capacity of Gas (C)

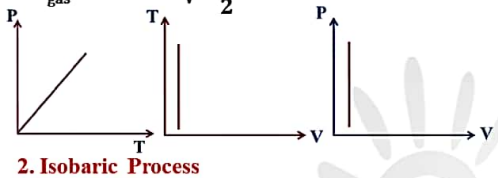
$C = \frac{\Delta Q}{n\Delta T}$ It depends on process

Thermodynamic Processes

1. Isochoric Process

$V = \text{Constant}$ $\Delta Q = n C_V \Delta T$ Bulk modulus is not defined

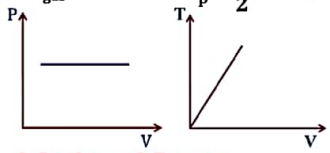
$W_{gas} = 0$ $C_V = \frac{f}{2}R$



2. Isobaric Process

$P = \text{constant}$ $\Delta Q = n C_P \Delta T$ Bulk modulus $B = 0$

$W_{gas} = nR\Delta T$ $C_p = \frac{f}{2}R + R$



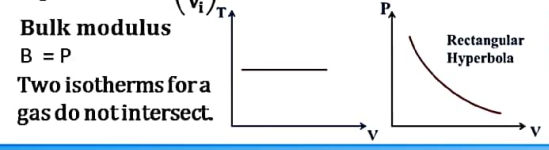
3. Isothermal Process

$T = \text{constant}$

$W_{gas} = nRT\ell n\left(\frac{V_f}{V_i}\right)$ C of this process is not defined

Bulk modulus $B = P$

Two isotherms for a gas do not intersect.



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First Law of thermodynamics

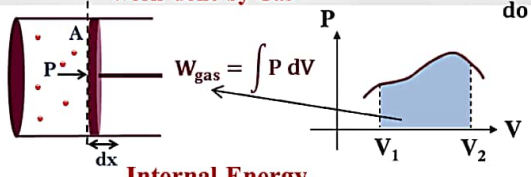
$\Delta Q = \Delta U + W$

Based on Conservation of Energy

	Definition	+ve	-ve
ΔQ	Heat supplied to gas	If heat is supplied to gas	Heat is taken from gas
ΔU	Change in U	If U increases	If U decreases
W	Work done by gas	If V increases	If V decreases

Thermodynamics

Work done by Gas



$W_{gas} = \int P\,dV$

Internal Energy

It is sum of molecular kinetic and potential energies in the reference relative to which COM (Centre of Mass) of the system is at rest.

$U = \frac{f}{2}nRT$

$\Delta U = U_f - U_i = \frac{f}{2}nR\Delta T$

$= \frac{f}{2}(P_fV_f - P_iV_i)$

$C_P - C_V = R$ Mayor's equation $\frac{C_P}{C_V} = \gamma$ Adiabatic constant

$C_V = \frac{f}{2}R$ $C_p = \frac{f}{2}R + R$ $\frac{C_P}{C_V} = \gamma$

Atomicity of gas	f	C_v	C_P	γ
Monoatomic	3	$\frac{3}{2}R$	$\frac{5}{2}R$	$\frac{5}{3} = 1.67$
Diatomic or Triatomic linear	5	$\frac{5}{2}R$	$\frac{7}{2}R$	$\frac{7}{5} = 1.40$
Polyatomic or Triatomic Non-linear	6	$\frac{6}{2}R = 3R$	$\frac{8}{2}R = 4R$	$\frac{4}{3} = 1.33$

$f = \frac{2}{\gamma - 1}$ $C_V = \frac{R}{\gamma - 1}$ $C_P = \frac{R\gamma}{\gamma - 1}$

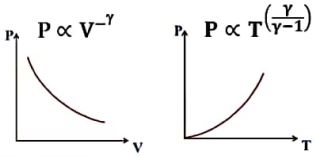
4. Adiabatic Process

$dQ = 0 \Rightarrow \Delta Q = 0$ $PV^{\gamma} = \text{Constant}$ $B = \gamma P$ $C = 0$

$W = -\Delta U$

$W_{gas} = -\frac{f}{2}nR\Delta T = \frac{nR\Delta T}{1-\gamma} = \frac{P_fV_f - P_iV_i}{1-\gamma}$

Two adiabatic curves for a particular gas do not intersect.



5. Polytropic Process

$PV^x = \text{Constant}$ $W_{gas} = \frac{nR\Delta T}{1-x}$

Slope of P–V curve $= -\frac{xP}{V}$ $B = -xP$

$C = R\left(\frac{1}{\gamma - 1} - \frac{1}{x - 1}\right)$

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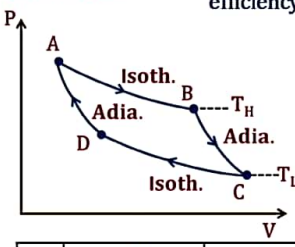
Thermodynamics

Carnot cycle

efficiency $'\eta' = \frac{W_{net}}{Q_{in}}$



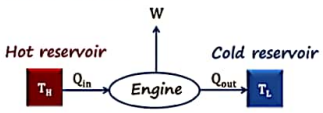
$$= \frac{|Q_{in}| - |Q_{out}|}{|Q_{in}|}$$

$$= 1 - \frac{|Q_{out}|}{|Q_{in}|}$$

$$\eta = 1 - \frac{T_L}{T_H}$$

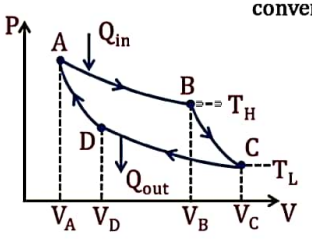
	W	ΔU	ΔQ
AB	$nRT_H \ell n\left(\frac{V_B}{V_A}\right)$	0	$nRT_H \ell n\left(\frac{V_B}{V_A}\right)$
BC	$\frac{nR(T_L - T_H)}{1-\gamma}$	$-\frac{nR(T_L - T_H)}{1-\gamma}$	0
CD	$nRT_L \ell n\left(\frac{V_D}{V_C}\right)$	0	
DA	$\frac{nR(T_H - T_L)}{1-\gamma}$	$-\frac{nR(T_H - T_L)}{1-\gamma}$	0

Heat Engine

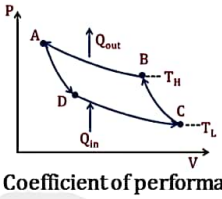


$$W = |Q_{in}| - |Q_{out}|$$

$$\text{Efficiency} = \frac{W_{net}}{Q_{in}} = 1 - \frac{|Q_{out}|}{|Q_{in}|}$$



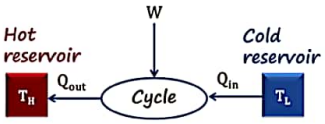
Reverse Carnot



Coefficient of performance (α)

$$\alpha = \frac{|Q_{in}|}{|Q_{out}| - |Q_{in}|} = \frac{T_L}{T_H - T_L}$$

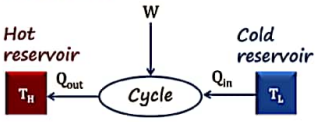
Heat Pump



Coefficient of performance (α)

$$= \frac{Q_{out}}{W}$$

Refrigerator



Coefficient of performance (α) $= \frac{Q_{in}}{W}$

$$= \frac{|Q_{in}|}{|Q_{out}| - |Q_{in}|}$$

Entropy

Related to disorder in system.

$$dS = \frac{dQ}{T}$$

For adiabatic process $\Delta S = 0$

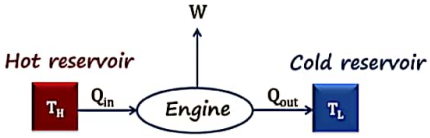
$$\Delta S = \int dS = \int \frac{dQ}{T}$$

Second Law of Thermodynamics

No process is possible whose sole result is the absorption of heat from a reservoir and the complete conversion of heat to work.

$$\text{Efficiency} = \frac{W_{net}}{Q_{in}} = 1 - \frac{|Q_{out}|}{|Q_{in}|}$$

$$\eta = 1 - \frac{T_L}{T_H}$$



Efficiency of Cyclic process must be less than 1.

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SIMPLE HARMONIC MOTION

$U = \frac{1}{2}kx^2$

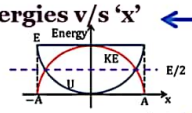
$KE = \frac{1}{2}k(A^2 - x^2)$

$KE + U = E = \frac{1}{2}kA^2$

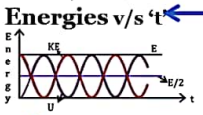
$U = \frac{1}{2}kA^2\sin^2(\omega t + \phi)$

$KE = \frac{1}{2}kA^2\cos^2(\omega t + \phi)$

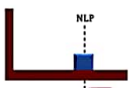
Energies v/s 'x'



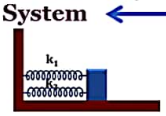
Energies v/s 't'



Spring Block System



$T = 2\pi\sqrt{\frac{m}{k}}$

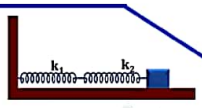


$k_{eq} = k_1 + k_2$

$T = 2\pi\sqrt{\frac{m}{k_{eq}}}$

$= 2\pi\sqrt{\frac{m}{k_1 + k_2}}$

In a spring block system, if an additional constant force (along line of SHM) is applied on the block then time period remains same.

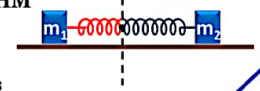


$T = 2\pi\sqrt{\frac{m}{k_{eq}}}$

$k_{eq} = \frac{k_1 k_2}{k_1 + k_2}$

Two Blocks SHM

COM

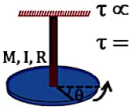


$\mu = \frac{m_1 m_2}{m_1 + m_2}$

Reduced Mass

$T_1 = 2\pi\sqrt{\frac{m_1 m_2}{k(m_1 + m_2)}} = 2\pi\sqrt{\frac{\mu}{k}}$

Torsional Pendulum

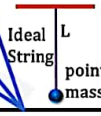


$\tau \propto -\theta$

$\tau = -C\theta$ (C = Torsional constant)

$T = 2\pi\sqrt{\frac{I}{C}}$

Simple Pendulum

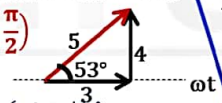


$T = 2\pi\sqrt{\frac{\mu}{k}}$

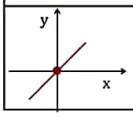
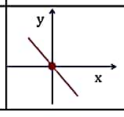
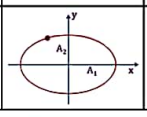
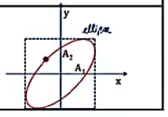
Composition of Two SHM's of same ω along mutually perpendicular directions

$x = 3\sin(\omega t) + 4\sin\left(\omega t + \frac{\pi}{2}\right)$

$x = 5\sin(\omega t + 53°)$



$\vec{x} = A_1\sin(\omega t)\hat{i}$ $\quad \vec{y} = A_2\sin(\omega t + \phi)\hat{j}$

When $\phi = 0$	When $\phi = \pi$	When $\phi = \frac{\pi}{2}$	When $\phi \neq 0, \frac{\pi}{2}, \pi$
$y = \frac{A_2}{A_1}x$	$y = -\frac{A_2}{A_1}x$	$\frac{x^2}{A_1^2} + \frac{y^2}{A_2^2} = 1$	
			

(1) Periodic $\quad F_{net} = -kx$ $\quad \omega = \sqrt{\frac{k}{m}}$

(2) Oscillatory $\quad a = -\omega^2 x$

(3) $|F| \propto |x|$ $\quad x = A\sin(\omega t + \phi)$

Time Period & Frequency $\quad T = \frac{2\pi}{\omega}$ $\quad f = \frac{1}{T} = \frac{\omega}{2\pi}$

Velocity Analysis $\quad x = A\sin(\omega t + \phi)$

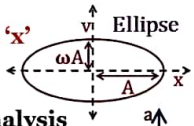
$v = \frac{dx}{dt} = A\omega\cos(\omega t + \phi)$

$v = \omega\sqrt{(A^2 - x^2)}$

Max velocity $\quad v_{max} = \omega A$ $\quad$ at $x = 0$ (Mean Position)

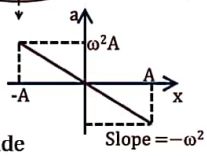
Min velocity $\quad v_{min} = 0$ $\quad$ at $x = \pm A$ (Extreme Position)

Graph b/w 'v' & 'x'



$\frac{x^2}{A^2} + \frac{v^2}{(\omega A)^2} = 1$

Acceleration Analysis



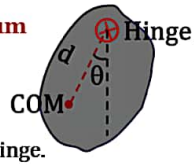
$a = -\omega^2 x$

$x = 2 + 1\sin(\omega t)$

Position $\quad$ Amplitude

eqm position

Physical Pendulum



$T = 2\pi\sqrt{\frac{I}{mgd}}$

I : MOI of system about hinge.

m : Mass of system

d : distance between COM and hinge.

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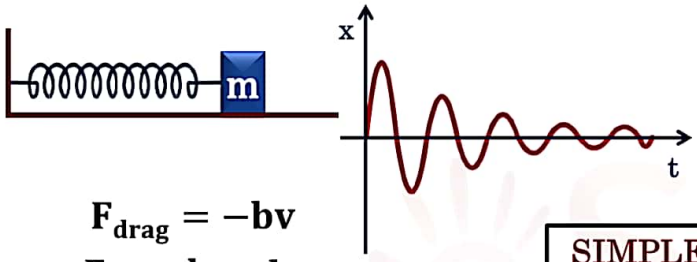
Damped SHM



$$F_{drag} = -bv$$

$$F = -kx - bv$$

$$x = Ae^{-bt/2m}\sin(\omega' t + \phi)$$

$$\omega' = \sqrt{\frac{k}{m} - \frac{b^2}{4m^2}}$$

$$E = \frac{1}{2}kA^2e^{-bt/m}$$

SIMPLE HARMONIC MOTION

Forced Oscillations and Resonance

$$F_{driving} = F_0 \sin(\omega_d t)$$

$$ma = -kx - bv + F_0 \sin(\omega_d t)$$

$$x = A\sin(\omega_d t + \phi)$$

$$A = \frac{F_0/m}{\sqrt{\left(\omega^2 - \omega_d^2\right)^2 + (b\omega_d/m)^2}}$$

If small damping, (b very small)

$$A = \frac{F_0/m}{(\omega^2 - {\omega_d}^2)}$$

$\omega_d \approx \omega \Rightarrow$ RESONANCE

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Wave on String

Power Transmission in Travelling Wave on String

$P = -T\left(\frac{\partial y}{\partial t}\right)\left(\frac{\partial y}{\partial x}\right)$ valid for all waves on string

Property of Source

$< P > = \frac{1}{2}\sqrt{T\mu}\ A^2\omega^2$

Property of medium

General Equation of Standing Wave

$y = 2A\sin(kx + \phi_1)\sin(\omega t + \phi_2)$

Amplitude of component wave = A

Coefficient of x = k

Wavelength of component waves = $\frac{2\pi}{k}$

Loop length = $\frac{\lambda}{2} = \frac{\pi}{k}$

Velocity of Wave on String

Tension T

$v_w = \sqrt{\frac{T}{\mu}}$

μ = mass per unit length

Stress

ρ

$v_w = \sqrt{\frac{Stress}{\rho}}$

Wave Function $y = f(x, t)$

Velocity of wave

$v_w = -\frac{\text{Coefficient of t}}{\text{Coefficient of x}}$

$y = A\sin(kx - \omega t)$

$v_w = -\frac{-\omega}{k} = \frac{\omega}{k}$

Wave travelling in + dir.

$y = A\sin(kx + \omega t)$

$v_w = -\frac{\omega}{k} = -\frac{\omega}{k}$

Wave travelling in − dir.

Sinusoidal Wave Equation

$y = A\sin(\omega t - kx + \phi)$

$\lambda = \frac{2\pi}{k}$ $T = \frac{2\pi}{\omega}$ Angular wave number, $k = \frac{2\pi}{\lambda}$

Velocity & Acceleration of Particle

$v_P = \frac{\partial y}{\partial t} = \omega\sqrt{A^2 - y^2}$

$y = A\sin(\omega t - kx)$ → Displacement

$a_P = \frac{\partial v_P}{\partial t} = -\omega^2 y$

Relation Between Particle Velocity & Wave Velocity

$v_P = -v_w\left(\frac{\partial y}{\partial x}\right)$ → Slope of the string at point x.

WAVES

Mechanical Waves

Medium is required

Waves on String, Sound Wave

Non-Mechanical Waves

Medium is not required

Light Wave

Transverse Wave

Constituents of the medium oscillates perpendicular to the direction of wave propagation.

Waves on String

Longitudinal Wave

Constituents of the medium oscillates along the direction of wave propagation.

Sound Wave

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Wave on String

Interference of Waves

Constructive Interference

Destructive Interference

Standing Waves

$y_{res} = 2A\sin(kx)\cos(\omega t)$

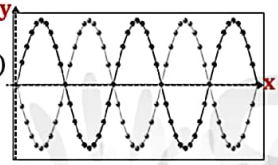
For $x = x_0$ Equation of Motion

$y = \underbrace{2A\sin(kx_0)}_{A'}\cos(\omega t)$

$y = A'\cos(\omega t)$

↓

SHM



$y_{res} = 2A\sin(kx)\cos(\omega t)$

$v_P = \frac{\partial y}{\partial t} = \omega\sqrt{A^2 - y^2}$

$a_p = \frac{\partial^2 y}{\partial t^2} = -\omega^2 y$

For Nodes - Amplitude = 0

$\sin(kx + \phi_1) = 0$

$kx + \phi_1 = n\pi$

For Antinodes - Amplitude = max

$\sin(kx + \phi_1) = \pm 1$

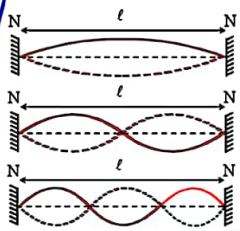
$(kx + \phi_1) = \left(n + \frac{1}{2}\right)\pi$

Energy in Standing Wave

For Node	For Anitnode
$KE = 0$	$PE = 0$
$\frac{\partial y}{\partial t} = 0$	$\frac{\partial y}{\partial x} = 0$
$P_{Node} = 0$	$P_{Antinode} = 0$

Power transmission through node & antinode is zero.
So, energy of one loop (even half loop) remains conserved.

Normal Modes String Fixed at Both Ends



$\frac{\lambda}{2} = \ell$ $f_0 = \frac{v}{2\ell}$ Fundamental Frequency (1) $\frac{n\lambda}{2} = \ell$

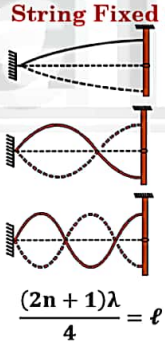
$\frac{2\lambda}{2} = \ell$ $f = \frac{2v}{2\ell}$ 2nd Harmonic, 1st Overtone (2) $f = \frac{nv}{2\ell}$

$\frac{3\lambda}{2} = \ell$ $f = \frac{3v}{2\ell}$ 3rd Harmonic, 2nd Overtone (3) $f = \frac{n}{2\ell}\sqrt{\frac{T}{\mu}}$

$\frac{n\lambda}{2} = \ell$ $f = \frac{nv}{2\ell}$ n th Harmonic, (n–1)th Overtone (4) $f = n f_0$

For fundamental frequency, n = 1

String Fixed at One End & Free at Other



$\frac{\lambda}{4} = \ell$ $f = \frac{v}{4\ell}$ Fundamental Frequency

$\frac{3\lambda}{4} = \ell$ $f = \frac{3v}{4\ell}$ 3rd Harmonic, 1st Overtone

$\frac{5\lambda}{4} = \ell$ $f = \frac{5v}{4\ell}$ 5th Harmonic, 2nd Overtone

$\frac{(2n+1)\lambda}{4} = \ell$ $f = \frac{(2n+1)v}{4\ell}$ (2n +1)Harmonic, nth Overtone

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Sound Waves

Variation of Excess Pressure in Gas Due to Propagation of Longitudinal Wave

$p = -B\left(\frac{\partial s}{\partial x}\right)$

↓ Excess pressure

$s = s_0 \sin(\omega t - kx)$

$p = p_0 \cos(\omega t - kx)$

$|p_0| = |Bks_0|$

Amplitude of excess pressure

Power Transmission in Sound Waves

$\text{Power} = -BA\left(\frac{\partial s}{\partial x}\right)\left(\frac{\partial s}{\partial t}\right)$

$< I >= \frac{1}{2}\sqrt{B\rho}\, s_0^2 \omega^2$

Property of medium — Property of source

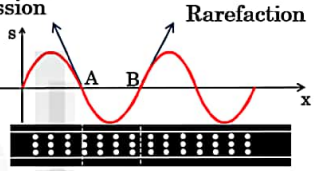
Equation of Sound Wave

Sinusoidal Wave Equation $s = s_0 \sin(\pm \omega t \pm kx + \phi)$

↓ displacement of particle present at x in x direction

Max Compressive Stress
Max. Density, Pressure
Compression

Max Tensile Stress
Min. Density, Pressure
Rarefaction

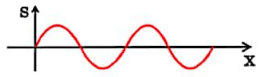


$s = s_0 \sin(\omega t - kx + \phi)$

$v_w = -\frac{\text{Coefficient of } t}{\text{Coefficient of } x} = \frac{\omega}{k}$

$v_P = -v_w\left(\frac{\partial s}{\partial x}\right)$

↓ Velocity of particle



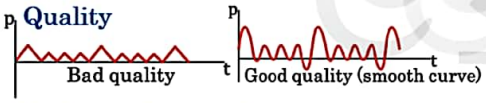
Characteristics of Sound

Pitch (Dominant Frequency)

Low Frequency → Low Pitch

High Frequency → High Pitch

Quality



Loudness (Intensity)

Sound level (SL) $= 10 \log_{10}\left(\frac{I}{I_0}\right)$

↓ measured in decibel (dB)

$I_0 = 10^{-12}\,\frac{\text{Watt}}{m^2}$

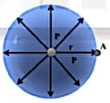
↓ Minimum audible intensity

Variation of Intensity

Point source

$I_A = \frac{P}{4\pi r^2}$

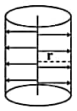
$I \propto \frac{1}{r^2}$



Line source

Power per unit length = P

$I = \frac{P\ell}{2\pi r\ell}$ $\quad I \propto \frac{1}{r}$



Velocity of Sound Wave in Gas

$v_w = \sqrt{\frac{\gamma P}{\rho}}$ $\quad v_w = \sqrt{\frac{\gamma RT}{M_0}}$ (T is in Kelvin)

On ↑ P if T is constant v_w will not change

At same T if humidity ↑, v_w increases ($\because M_0 \downarrow$)

Velocity of sound wave in a thin solid rod $= \sqrt{\frac{Y}{\rho}}$

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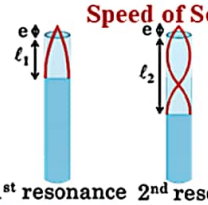
Sound Waves

Resonance Tube Method to Calculate Speed of Sound in Air



1st resonance 2nd resonance

$v = f\lambda$

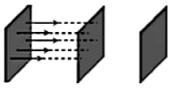
$v = 2f(\ell_2 - \ell_1)$

$e = 0.3\,d$

diameter of tube

Wavefront

Point source
Line source

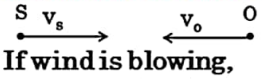


Cylindrical wavefronts
Spherical wavefronts
Planar wavefronts

Change in wavelength due to motion of a sound source

$$\lambda' = \frac{v_w \pm v_s}{f}$$

Change in frequency observed due to motion of both source & observer



$$f' = \left(\frac{v_w + v_0}{v_w - v_S}\right) f$$

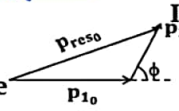
If wind is blowing, take its effect also

Interference of Sound Waves

$p_1 = p_{1_0}\sin(kx - \omega t)$

$p_2 = p_{2_0}\sin(kx - \omega t + \phi)$

By Superposition Principle



$(p_{res_0})^2 = p_{1_0}^2 + p_{2_0}^2 + 2\,p_{1_0}p_{2_0}\cos\phi$

$I_{res} = I_1 + I_2 + 2\sqrt{I_1}\sqrt{I_2}\cos\phi \quad (I \propto p_o^2)$

Beat frequency $= \Delta f = f_1 - f_2$

Constructive Interference

$(p_{res_0})_{max} = p_{1o} + p_{2o}$

$(I_{res})_{max} = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2$

$\Delta x = 0, \lambda, 2\lambda, 3\lambda \ldots = n\lambda$

Constructive Interference

Destructive Interference

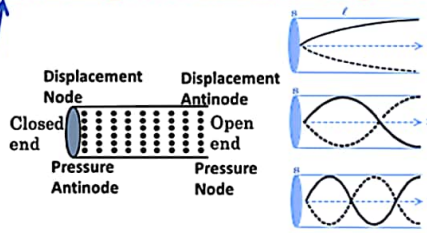
Destructive Interference

$(p_{res_0})_{min} = |p_{1o} + p_{2o}|$

$(I_{res})_{min} = \left(\sqrt{I_1} - \sqrt{I_2}\right)^2$

$\Delta x = 0.5\lambda, 1.5\lambda, 2.5\lambda \ldots = \left(n + \frac{1}{2}\right)\lambda$

Standing Wave Inside an Organ Pipe Closed at One End



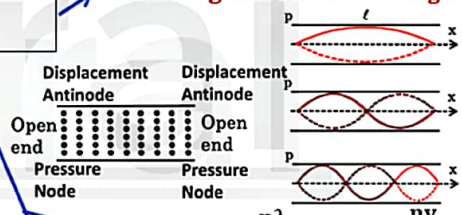
$\frac{\lambda}{4} = \ell \quad f = \frac{1v}{4\ell}$ Fundamental frequency

$\frac{3\lambda}{4} = \ell \quad f = \frac{3v}{4\ell}$ 3rd Harmonic 1st overtone

$\frac{5\lambda}{4} = \ell \quad f = \frac{5v}{4\ell}$ 5th Harmonic 2nd overtone

$\frac{(2n+1)\lambda}{4} = \ell \quad f = \frac{(2n+1)v}{4\ell}$ $(2n+1)^{th}$ Harmonic n^{th} overtone

Standing Wave Inside an Organ Pipe Open at Both End



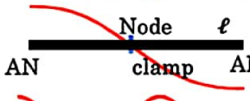
$\frac{\lambda}{2} = \ell \quad f_o = \frac{1v}{2\ell}$ Fundamental frequency

$\frac{2\lambda}{2} = \ell \quad f = \frac{2v}{2\ell}$ 2nd Harmonic 1st overtone

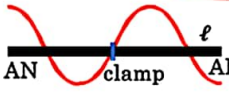
$\frac{3\lambda}{2} = \ell \quad f = \frac{3v}{2\ell}$ 3rd Harmonic 2nd overtone

$\frac{n\lambda}{2} = \ell \quad f = \frac{nv}{2\ell}$ n^{th} Harmonic $(n-1)^{th}$ overtone

Standing Wave in Solids



$\frac{\lambda}{2} = \ell \quad f = \frac{1}{2\ell}\sqrt{\frac{Y}{\rho}}$ fundamental mode



$\frac{3\lambda}{2} = \ell \quad f = \frac{3}{2\ell}\sqrt{\frac{Y}{\rho}}$ 1st overtone 3rd harmonic

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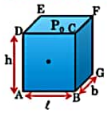
Fluid Mechanics- Statics & Dynamics

Force By Liquid

Reading =mg= ρagh

Force Applied by Liquid on Vertical Surface



$$F = \left(P_0 + \frac{\rho g h}{2}\right) h\ell$$

Buoyant Force

Buoyant force is equal to weight of the fluid displaced.
Buoyant force depends on g_{eff}
Buoyant force acts opposite to g_{eff}

$BF = \rho_f g h A$

Archimedes Principle

Loss of weight of a body submerged (partially or completely) in a fluid is equal to the weight of the fluid displaced.

Weight of fluid displaced = $\rho_\ell V_S g = BF$

If $\rho_b < \rho_\ell$; then body will float

If $\rho_b = \rho_\ell$; body will just float with fully submerged

If $\rho_b > \rho_\ell$; then body will sink

Law of Floatation

For Floating : $\frac{V_S}{V_b} = \frac{\rho_b}{\rho_\ell}$

Fraction of vol. submerged = ratio of density of body and fluid

Conditions of Ideal Fluid Flow

Fluid is Incompressible and Non- Viscous).

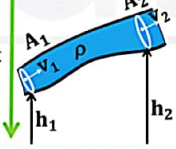
Flow is Irrotational & Steady

Volume flow rate.	Mass flow rate
Volume flowing through per unit time.	Mass flowing through per unit time.
$\frac{dV}{dt} = Av$	$\frac{dm}{dt} = \rho Av$

Bernoulli's Principle

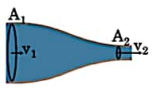
$$P + \rho g h + \frac{1}{2}\rho v^2 = \text{Constant}$$

Based on law of conservation of energy

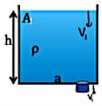


Equation of Continuity

$A_1 v_1 = A_2 v_2$



Speed of Efflux: Torricelli's Law



$v = \sqrt{2gh}$

The value of this force acting on unit area at any point is called Pressure at that point.

$\text{Pressure} = \frac{dF_1}{dA_1}$ → Scalar Quantity

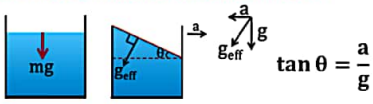
SI unit is N/m^2 = Pascal (Pa)

1 bar = 10^5 Pa

1 atm = 101325 Pa ≈ 10^5Pa

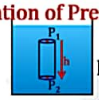
1 atm = 1.01325 bar ≈ 1 bar

Ideal fluid cannot sustain shear stress

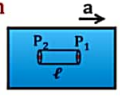


$\tan\theta = \frac{a}{g}$

Variation of Pressure with Depth

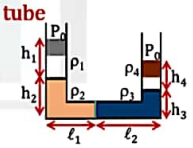


$P_2 = P_1 + \rho_\ell g h_1$

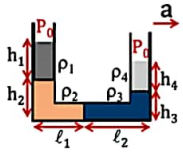


$P_2 = P_1 + \rho a \ell$

U-shaped tube

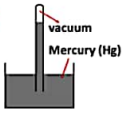


$P_0 + \rho_1 g h_1 + \rho_2 g h_2 - \rho_3 g h_3 - \rho_4 g h_4 = P_0$



$P_0 + \rho_1 g h_1 + \rho_2 g h_2 - \rho_2 a \ell_1 - \rho_3 a \ell_2 - \rho_3 g h_3 - \rho_4 g h_4 = P_0$

Barometer



Pascal's Law

Whenever external pressure is given at any part of fluid it is transmitted undiminished and equally in all direction

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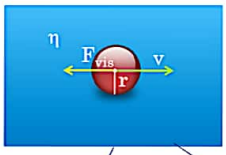
Stokes' Law



$F_{vis} = 6\pi\eta r v$

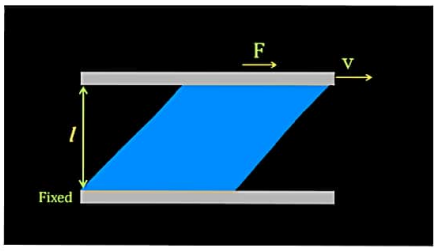
$\overrightarrow{F_{vis}}$ is opp. to $\vec{v}$

Viscosity exists when there is relative motion between layers of the liquid.

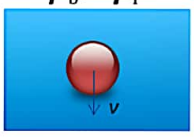
Viscosity

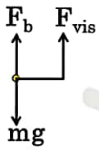
Reynolds Number (R_e)

$$R_e = \frac{\rho v d}{\eta}$$



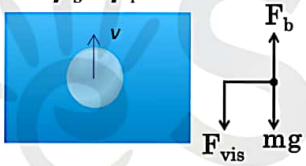
$\rho_b > \rho_f$



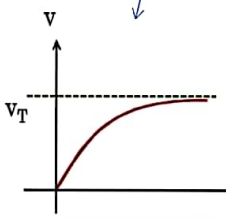


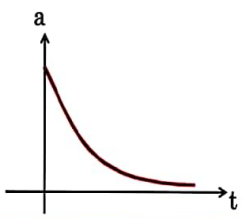
$$V_T = \frac{2}{9}\frac{(\rho_b - \rho_f) r^2 g}{\eta}$$

$\rho_b < \rho_f$



$$V_T = \frac{2}{9}\frac{(\rho_f - \rho_b) r^2 g}{\eta}$$





If $R_e < 1000$	Flow is steady
If $1000 < R_e < 2000$	Flow is unstable
If $R_e > 2000$	Flow is turbulent

Largest velocity till which flow is steady is called Critical Velocity.

$F = \eta A \left(\frac{v}{\ell}\right)$ → Velocity gradient

↓

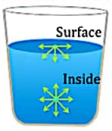
Coefficient of viscosity

SI unit of η is Poiseuille (Pl)

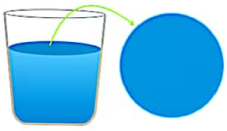
CGS unit is Poise

1 Poise = 0.1 Poiseuille

Surface tension

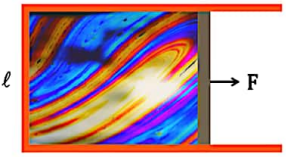


$U_{surface} > U_{inside}$



Surface Tension (S) $= \frac{\text{Force}}{\text{Length}} = \frac{F}{L}$

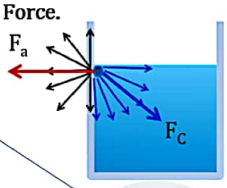
Surface Energy



Surface Energy = Surface Tension × Surface Area

$U = S \times (\ell d) \times 2$

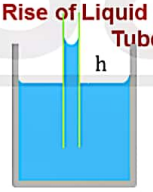
Force between different types of molecules is called Adhesive Force.



Force between same types of molecules is called Cohesive Force.

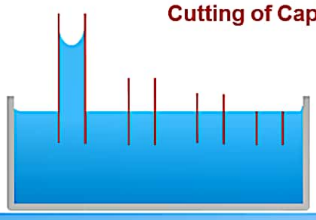
Surface Tension

Rise of Liquid in Capillary Tube



$$h = \frac{2S}{\rho g R} = \frac{2S}{\rho g r}\cos\theta_C$$

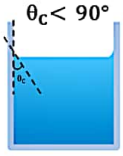
Cutting of Capillary Tube

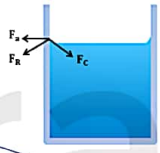


$$h = \frac{2S}{\rho g R} = \frac{2S}{\rho g r}\cos\theta_C$$

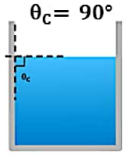
Contact Angle (θc)

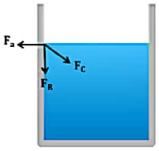
Glass Vessel – Water $\theta_C < 90°$



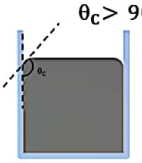


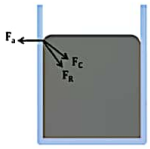
Silver Vessel – Water $\theta_C = 90°$





Glass Vessel – Mercury $\theta_C > 90°$





Excess Pressure

Inside a Drop in Air $\frac{2S}{R}$

Thin Soap Bubble in Air $\frac{4S}{R}$

Air Bubble in Water $\frac{2S}{R}$

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